REMARKS

Entry of the foregoing amendments, and reexamination and reconsideration of the subject application, pursuant to and consistent with 37 C.F.R. § 1.104 and § 1.112, and in light of the following remarks, are respectfully requested.

The indication of allowable claims is gratefully acknowledged.

Amendments

Claims 7, 8, and 10 have been amended to address the objections with regard to the lack of antecedent basis, including amending claim 9 to provide antecedent basis for claim 10. Claim 1 is amended to be consistent with claim 9 in reciting that the meshes are compressed. No new matter is added.

Drawings

A replacement set of drawings is submitted.

Claim Objections

Claim 3 was found objectionable because the recitation of "type 309 stainless steel" is allegedly vague and indefinite. This objection is respectfully traversed.

"Type 309" stainless steel is a well-known and utilized definition and description of a Ni-Cr steel used by those of ordinary skill in the art. The AISI (American Iron and Steel Institute) "type" is a commonly used designation, as shown on the enclosed copy from efunda.com, which lists alternative DIN (Germany), UNI (Italy), and ASTM and MIL-SPEC equivalents, as well as the composition of Type 309. The technical data sheets from Allegheny Ludlum and ASM International (copies attached) also give the same and additional information. As shown on these attachments, "Type 309" is a know industry standard for the composition and properties of a certain Ni-Cr stainless steel.

In light of the foregoing and the attachments, the rejection fails to explain why the claim terminology is vague and indefinite. To the contrary, one of ordinary skill in this art (or others) specifying "Type 309" stainless steel would

have a clear understanding of the composition and properties being specified. Accordingly, the use of the same terminology in the claim is clear and definite. It is also noted that same terminology of "Type 309" stainless steel appears in the claims of U.S. Pat. Nos. 5,024,422, 4,946,083, and 4,670,242, providing further evidence that the Office considers such terminology clear and definite. Accordingly, withdrawal of this objection is now proper.

Rejection under 35 U.S.C. 103

The rejection of claims 1-3, 5-7, 9, 11, 13, and 15 as obvious over the combination of Jaraczewski (*et al.*) in view of Weil is respectfully traversed.

The rejected independent claims 1 and 9 recited a "compressed" wire mesh seal element. The "torque transmitting layers 12 and 14" of Jaraczewski are neither a compressed wire mesh nor a seal. Rather, they are "flat" braided materials as disclosed at column 4 (ln. 55-65). Jaraczewski also teaches away from using "round" braided materials, as is confirmed at column 4 (ln. 59-61) because of the larger torque-conveying capacity of flat wires and column 5 (ln. 9-23) wherein flat ribbon materials are disclosed. Jaraczewski also teaches away from using a round wire because of size considerations in a living vessel (col. 5, ln. 3-8). The mesh layers in this reference are used to transmit torque to a catheter to control its shape and direction in a vas, and are not related to any sealing function; in fact, the mesh layers are encapsulated in the catheter.

Weil discloses providing improved thermal shielding to fluid and vacuum hoses in an engine compartment, wherein the inner <u>uncompressed</u> woven mesh is harder to allow it to spring back into shape, and the outer <u>uncompressed</u> woven mesh is softer to avoid tearing the foil layer (30). Neither mesh is compressed, and neither performs any sealing function; the intent to for heat protection, not for controlling the flow of gas (*i.e.*, a "seal" as recited). Weil teaches that the outer mesh can be glass fiber (col. 4, first paragraph).

There is no suggestion or teaching in either reference regarding corrosion resistance: Jaraczewski is directed to catheters where biocompatibility is an issue (col. 4, ln. 44), and in Weil only thermal resistance is an issue. Neither reference teaches accommodating corrosive hot combustion gases.

The prior art structures are not capable of performing the intended use absent modification, even in combination. Jaraczewski does not appear to disclose the type of steel used (other than "stainless") and Weil discloses only type 304 SS (col. 5, ln. 22). Neither reference discloses a compressed mesh able to function in the environment of a catalytic converter. Jaraczewski teaches away from a round wire, and Weil does not teach the two mesh layers together. If the teaching of Jaraczewski is used to place the meshes together (which is contrary to Weil), the teaching is away from using a round wire for one of the meshes, and the combination still fails to teach using compressed meshes that will function in the hot exhaust gas environment. As neither reference is directed to this sort of corrosive environment, the improper picking and choosing of teachings from the references would appear to be based on improper hindsight reconstruction. One would have to place the meshes together (contrary to Weil), using only one flat wire (contrary to Jaraczewski where both meshes are made of flat materials), compress the meshes (as taught by neither), and use stainless steel suitable for a corrosive environment (also taught by neither). In fact, as the claim is to be interpreted in light of the specification, it is clear that the planar shape of the meshes is drastically changes by being compressed into the seal element, and both compressing the meshes and a seal element are recited in the claim. Accordingly, this rejection should now be withdrawn.

Alloy™ DIGEST

J & L TYPE 309

DATA ON WORLDWIDE METALS AND ALLOYS

Filing code: SS-896
Stainless Steel

December 2003

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Fax 440-338-4634 www.asminternational.org

J & L TYPE 309
(Heat-Resistant Austenitic Stainless Steel)

Type 309 (UNS S30900) is an austenitic chromium-nickel stainless steel widely used for elevated-temperature services. It has a good combination of oxidation resistance and corrosion-resisting properties. The alloy is essentially nonmagnetic when annealed and become slightly magnetic when cold worked. It is intended primarily for high-temperature applications at 816 °C (1500 °F) or higher where resistance to oxidation and/or corrosion is required.

Chemical Composition, wt.%:

	Typical analysis	Major elements
Carbon	0.06	0.20 max
Manganese	1.75	2.00 max
Phosphorus	0.020	...
Sulfur	0.002	...
Silicon	0.50	1.00 max
Chromium	23.00	22.00–24.00
Nickel	13.00	12.00–15.00
Iron	bal	bal

Physical Properties:

Density, kg/m^3 (lb/in.^{3})	7992 (0.289)
Specific gravity	7.86–7.94
Melting temperature, °C (°F)	1399–1454 (2550–2650)
Thermal conductivity, W/m · K (Btu/(ft · h · °F))	
20–100 °C (68–212 °F)	15.6 (9.0)
20–500 °C (68–932 °F)	18.7 (10.8)
Magnetic permeability at 200 H	1.02
Coefficient of linear thermal expansion, 10^{-6}/K (10^{-6}/°F)	
20–100 °C (68–212 °F)	15.6 (8.7)
20–500 °C (68–932 °F)	17.6 (9.8)
20–1000 °C (68–1832 °F)	19.4 (10.8)
Specific heat capacity, J/kg · K (Btu/lb · °F)	502 (0.12)
Electrical resistivity, μΩ · m (Ω circular-mil/ft)	
20 °C (68 °F)	0.78 (469)
649 °C (1200 °F)	1.148 (691)

Mechanical Properties:

(Typical)

Yield strength, MPa (ksi)	
No. 1 /2D finish, annealed	303 (44)
No. 2 /2B finish, skin passed	324 (47)
Tensile strength, MPa (ksi)	
No. 1 /2D finish, annealed	586 (85)
No. 2 /2B finish, skin passed	607 (88)
Elongation in 2 in., %	
No. 1 /2D finish, annealed	46
No. 2 /2B finish, skin passed	46
Hardness, HRB	
No. 1 /2D finish, annealed	81
No. 2 /2B finish, skin passed	85
Young's modulus, GPa (10^6 psi)	193–207 (28–30)
Shear modulus, GPa (10^6 psi)	77.2 (11.2)

See also Fig. 1.

Heat Treatment:

Processing Annealing. Cool rapidly from 1040–1120 °C (1900–2050 °F). Air cooling from annealing temperatures may be employed for light sections; otherwise water quenching is necessary.

Response to Heat Treatment. Like other steels that retain an austenitic structure at room temperature, this alloy is not hardenable through heat treatment. Higher mechanical properties can only be obtained by hot working at low temperatures or by cold rolling.

Stress Relieving. The recommended temperature range for stress relieving is 205–400 °C (400–750 °F).

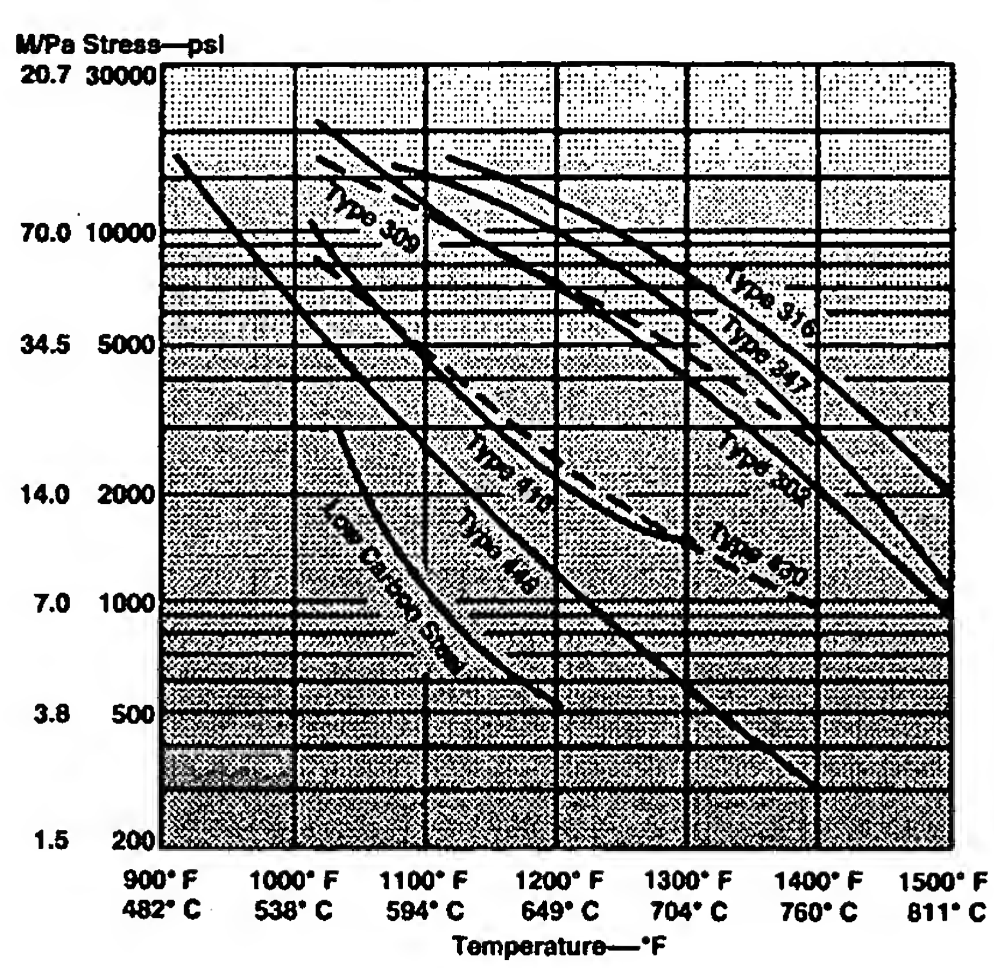

Fig. 1 Creep strength (1% creep in 10,000 h)

Workability:

Hot Working. Initial forging and pressing temperature is 1120–1230 °C (2050–2250 °F). Finishing temperature is 925 °C (1700 °F).

Forming. This grade can be formed into most desired shapes. However, since it work hardens, an anneal should precede and follow each severe cold-forming operation.

Weldability:

This grade is usually welded by the electric arc or gas fusion processes. Type 309 or Type 309Cb filler metal or electrodes are used.

Corrosion Resistance:

Type 309 has good general corrosion resistance and shows excellent aqueous corrosion resistance. It is as resistant as type 304 to the same aqueous media. Due to its higher chromium and nickel contents, it is somewhat more resistant than the 18-8 grades in some environments. Stainless steels possess increasing resistance to oxidation as their chromium content is raised. Type 309 resists oxidation up to 1093 °C (2000 °F). Where intermittent heating and cooling applications are involved, type 310 is preferred because it forms a tightly adhering scale; whereas type 309 tends to shed its scale under the same cycles. For continuous service, the maximum recommended temperature is 1093 °C (2000 °F) and for intermittent service 982 °C (1800 °F).

Specification Equivalents:

UNS S30900

ASTM A 240

ASME SA 240

General Characteristics:

This alloy is an austenitic chromium nickel modification of J&L stainless type 304 with superior heat resistance characteristics. It offers slightly better corrosion resistance than type 304 because of the higher percentages of both chromium and nickel. In addition, this alloy possesses better creep strength than other austenitic and straight chromium grades (see Fig. 1). This alloy has resistance to oxidation up to 1093 °C (2000 °F) for continuous service.

Product Forms Available:

J & L Type 309 is available as ingots, slabs, hot bands, sheet, and strip. It is available as cold-rolled sheet where the term "stainless steel sheet" refers to sheet <0.1874 in. thick and >24 in. wide. The thickness range is 0.015–0.1874 in. The width range is 24–60 in. inclusive. Length may be up to 240 in., with longer sheets available on inquiry. Normally 175 in. is the maximum for resquared sheet, but lengths to 240 in. can be resquared on inquiry. Coil inside diameter (ID) can be 12, 20, or 24 in.

Edges are available as No. 3 slit edge, No 2 mill edge (unfinished edge), and resquared or sheared edge.

Available tempers include annealed soft and most standard temper ranges, $^1/_4$ through full hard.

Continuous mill plate is available in coil or cut length, annealed and pickled, mill edge, or slit edge. Thicknesses available are $^3/_{16}$, $^1/_4$, and $^5/_{16}$ in. Width is 60 in maximum. Length is 480 in. maximum. Inquire to the manufacturer about slit coils for Gauer bar.

Hot-rolled annealed and pickled sheet is available as a standard grade with thickness 0.095–0.300 in. and width 24–60 in.

Applications:

Typical applications are aircraft heaters, chemical processing equipment, dryers, dyehouse equipment, furnace parts, heat exchangers, heat treating equipment, oil burner parts, paper mill equipment, recuperators, and skid rails.

Producer:

J & L Specialty Steel, LLC
Arcelor Group
Pittsburgh, PA 15230-3373
(412) 375-1600
(800) 553-9235

ISSN: 002-614X SS-896B

Allegheny Ludlum
An Allegheny Technologies Company

TECHNICAL DATA BLUE SHEET

Stainless Steel

Types 309 (UNS S30900), 309S (UNS S30908), 309H (UNS S30909), 309Si

Types 310 (UNS S31000), 310S (UNS S31008), 310H (UNS S31009), 310Si

GENERAL INFORMATION

Allegheny Ludlum's Type 309 and Type 310 austenitic stainless steels are typically used for elevated temperature applications. Their high chromium and nickel contents provide comparable corrosion resistance, superior resistance to oxidation and the retention of a larger fraction of room temperature strength than the common austenitic alloys like Type 304. Both alloys are available in plate, sheet, and strip product forms in a wide variety of sizes and finishes.

APPLICATIONS

Higher alloyed stainless steels generally exhibit excellent elevated temperature strength along with resistance to creep deformation and environmental attack. As such, they are used widely in the heat treatment industry for furnace parts such as conveyor belts, rollers, burner parts, refractory supports, retorts and oven linings, fans, tube hangers, and baskets and trays to hold small parts. These grades are also used in the chemical process industry to contain hot concentrated acids, ammonia, and sulfur dioxide. In the food processing industry, they are used in contact with hot acetic and citric acid.

CHEMICAL COMPOSITION

Chemistries are taken from ASTM A167 and ASTM A240 specifications unless otherwise noted.

	Type 309 (UNS S30900)	Type 309S (UNS S30908)	Type 309H (UNS S30909)	Type 309Si (DIN 1.4828)	Type 310 (UNS S31000)	Type 310S (UNS S31008)	Type 310H (UNS S31009)	Type 310Si (DIN 1.4841)
C	0.20	0.08	0.04 min 0.10 max	0.20	0.25	0.08	0.04 min 0.10 max	0.20
N	—	—	—	0.11	—	—	—	0.11
Mn	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
P	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
S	0.030	0.030	0.030	0.015	0.030	0.030	0.030	0.015
Si	0.75	0.75	0.75	1.50 min 2.50 max	1.50	1.50	0.75	1.50 min 2.50 max
Cr	22.00 min 24.00 max	22.00 min 24.00 max	22.00 min 24.00 max	19.00 min 21.00 max	24.00 min 26.00 max	24.00 min 26.00 max	24.00 min 26.00 max	24.00 min 26.00 max
Ni	12.00 min 15.00 max	12.00 min 15.00 max	12.00 min 15.00 max	11.00 min 13.00 max	19.00 min 22.00 max	19.00 min 22.00 max	19.00 min 22.00 max	19.00 min 22.00 max
Fe	Balance	Balance	Balance	Balance	Balance	Balance	Balance	Balance

Alloy composition—all values in weight percent, maximum levels unless a range is specified.

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Data are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown herein.

PHYSICAL PROPERTIES

	Type 309		Type 310	
Density	lb_m/in^3	g/cm^3	lb_m/in^3	g/cm^3
at 68°F (20°C)	0.29	8.03	0.29	8.03
Coefficient of Thermal Expansion	(µin/in)·°F	(µm/m)·K	(µin/in)·°F	(µm/m)·K
at 68°–212°F (20°–100°C)	8.7	15.6	8.8	15.9
at 68°–932°F (20°–500°C)	9.8	17.6	9.5	17.1
at 68°–1832°F (20°–1000°C)	10.8	19.4	10.5	18.9
Electrical Resistivity	µΩ·in	µΩ·cm	µΩ·in	µΩ·cm
at 68°F (20°C)	30.7	78.0	30.7	78.0
at 1200°F (648°C)	45.1	114.8	—	—
Thermal Conductivity	Btu/hr·ft·°F	W/m·K	Btu/hr·ft·°F	W/m·K
at 68°–212°F (20°–100°C)	9.0	15.6	8.0	13.8
at 68°–932°F (20°–500°C)	10.8	18.7	10.8	18.7
Specific Heat	$Btu/lb_m\cdot°F$	J/kg·K	$Btu/lb_m\cdot°F$	J/kg·K
at 32°–212°F (0°–100°C)	0.12	502	0.12	502
Magnetic Permeability (annealed)[1]				
at 200H		1.02		
Modulus of Elasticity (annealed)[2]	psi		GPa	
in tension (E)	29×10^6		200	
in shear (G)	11.2×10^6		77	

1 Common value for both alloys, no units
2 Common value for both alloys

General physical properties for base Type 309 and Type 310 austenitic stainless steels

TYPICAL SHORT–TERM MECHANICAL PROPERTIES

All tensile testing was done in accordance with ASTM E8. The data consists of the average results from a minimum of two and as many as ten samples. Yield strength was determined by the 0.2% offset method. Plastic elongation is as measured in a two inch gauge length.

	Test Temperature		Yield Strength		Tensile Strength		Elongation
	(°F)	(°C)	ksi	MPa	ksi	MPa	%
TYPE 309	77	25	42.0	290	90.0	621	49
	400	204	35.0	241	80.0	552	46
	800	427	30.0	207	72.0	497	40
	1000	538	24.0	166	66.0	455	36
	1200	649	22.0	152	55.0	379	35
	1400	760	20.0	138	36.0	248	40
	1600	871	18.5	128	21.0	145	50
	1800	982	—	—	10.0	69	65

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TYPE 309S

Test Temperature (°F)	Test Temperature (°C)	Yield Strength ksi	Yield Strength MPa	Tensile Strength ksi	Tensile Strength MPa	Elongation %
77	25	50.9	351	97.1	670	44.6
200	93	44.7	308	88.8	612	29.0
400	204	37.4	258	81.7	563	34.5
600	316	33.4	230	80.2	553	31.6
800	427	29.6	204	77.1	531	32.1
900	482	30.4	210	74.7	515	32.0
1000	538	26.7	184	71.2	491	26.6
1100	593	26.5	182	65.6	452	25.5
1200	649	24.7	170	55.9	386	28.8
1300	704	23.7	163	55.7	384	—
1400	760	22.2	153	36.0	248	22.5
1500	816	20.1	138	24.7	170	64.8
1600	871	16.6	114	20.7	142	73.3
1700	927	13.1	90	15.4	106	78.7
1800	982	8.2	56	10.8	74	—
1900	1038	4.6	32	6.6	46	—

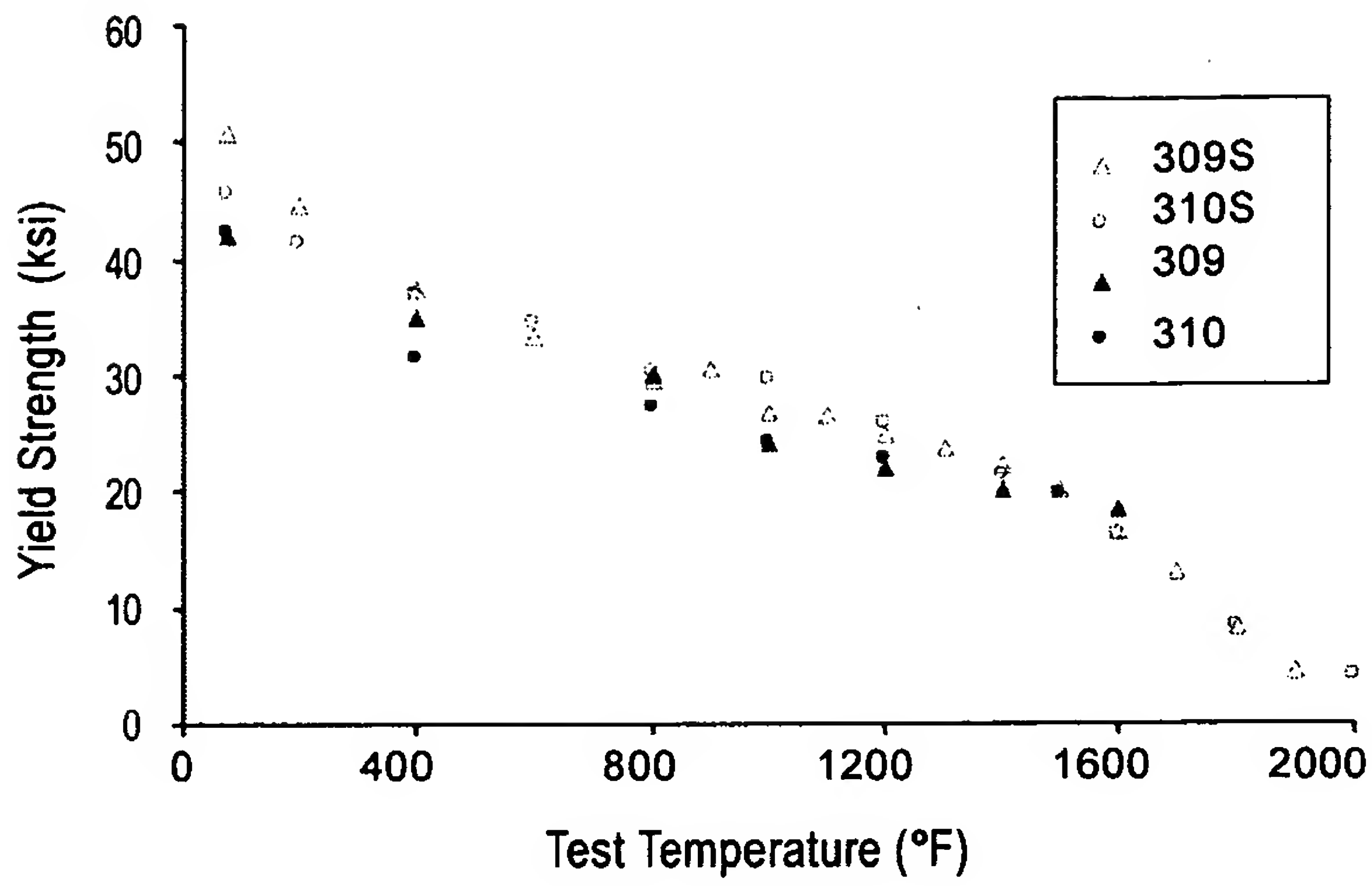
TYPE 310

Test Temperature (°F)	Test Temperature (°C)	Yield Strength ksi	Yield Strength MPa	Tensile Strength ksi	Tensile Strength MPa	Elongation %
77	25	42.4	292	89.5	617	45
400	204	31.5	217	76.6	528	37.5
800	427	27.2	188	74.8	516	37
1000	538	24.2	167	70.1	483	36
1200	649	22.6	156	57.2	394	41.5
1500	816	19.7	136	30.3	209	66
1800	871	—	—	11.0	76	65
2000	1093	—	—	7.0	48	77

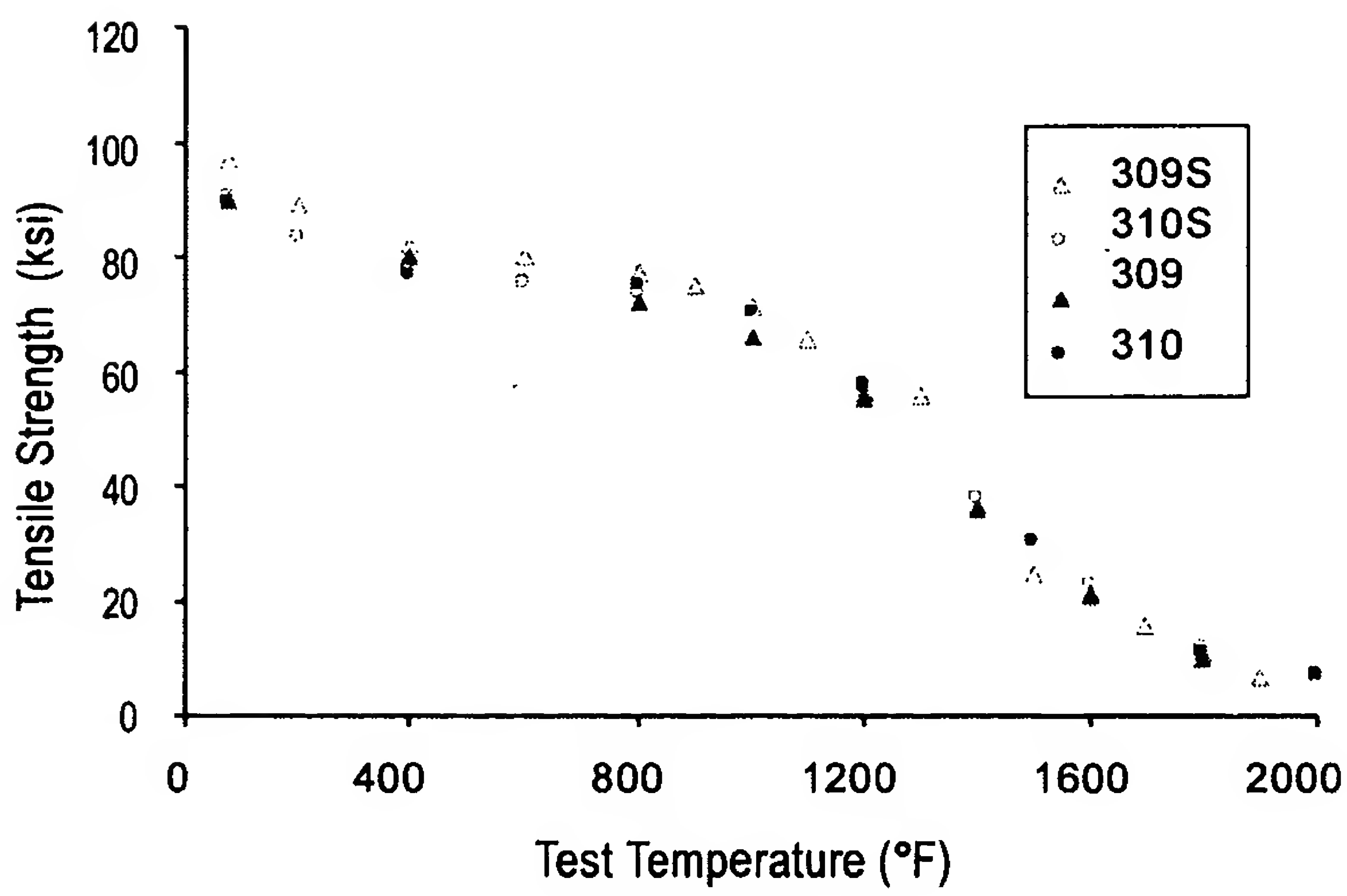
TYPE 310S

Test Temperature (°F)	Test Temperature (°C)	Yield Strength ksi	Yield Strength MPa	Tensile Strength ksi	Tensile Strength MPa	Elongation %
77	25	45.6	314	90.5	624	42.6
200	93	41.4	286	83.4	575	41.3
400	204	36.9	254	77.3	533	35.8
600	316	34.6	239	75.2	519	35.0
800	427	30.3	209	73.6	508	33.5
1000	538	29.4	203	70.2	484	37.0
1200	649	25.8	178	57.0	393	32.0
1400	760	21.4	147	37.7	260	54.0
1600	871	16.1	111	22.5	155	56.5
1800	982	8.2	56	11.8	81	93.3
2000	1093	4.0	27	6.5	44	121.0

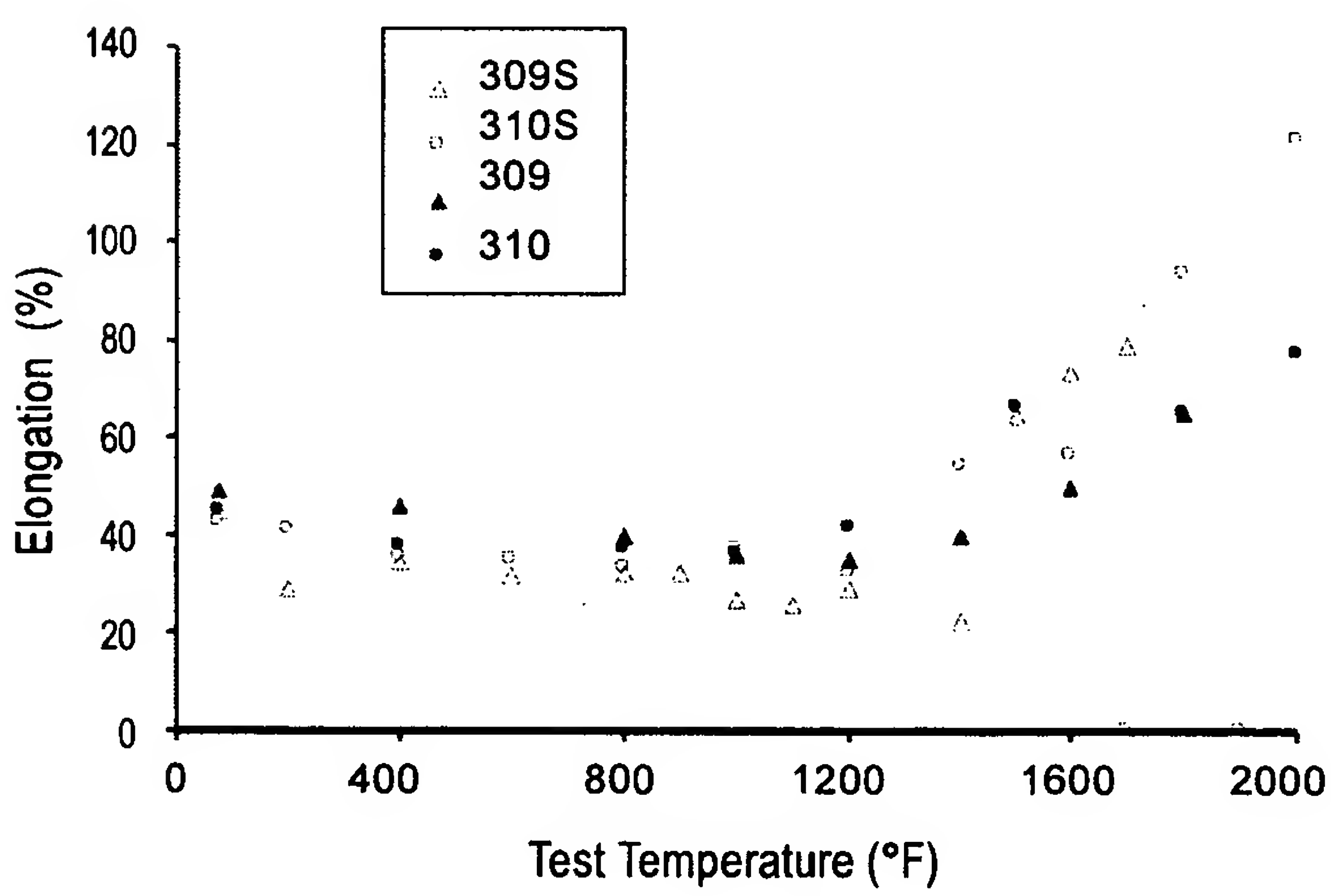
Data are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown herein.



Yield strength
(0.2% offset)
in tension



Tensile strength

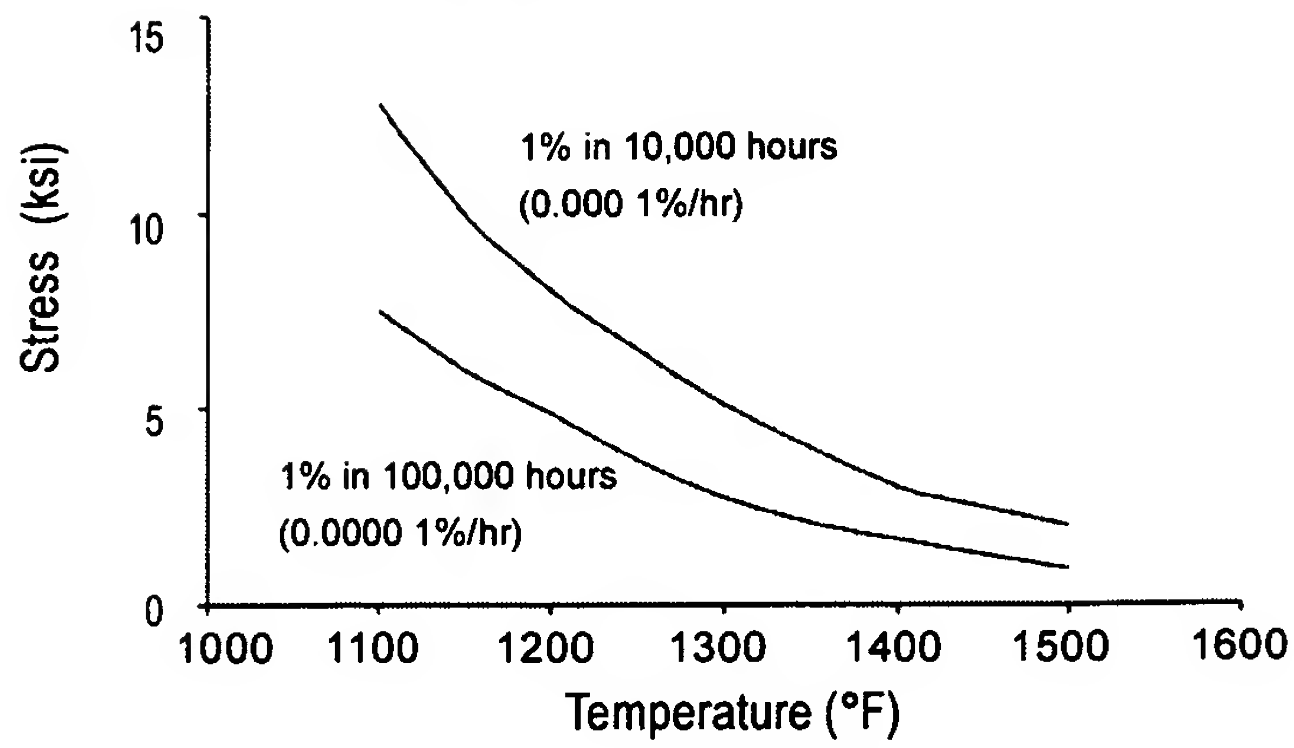


Total elongation
(in a 2 inch gauge length)
in tension

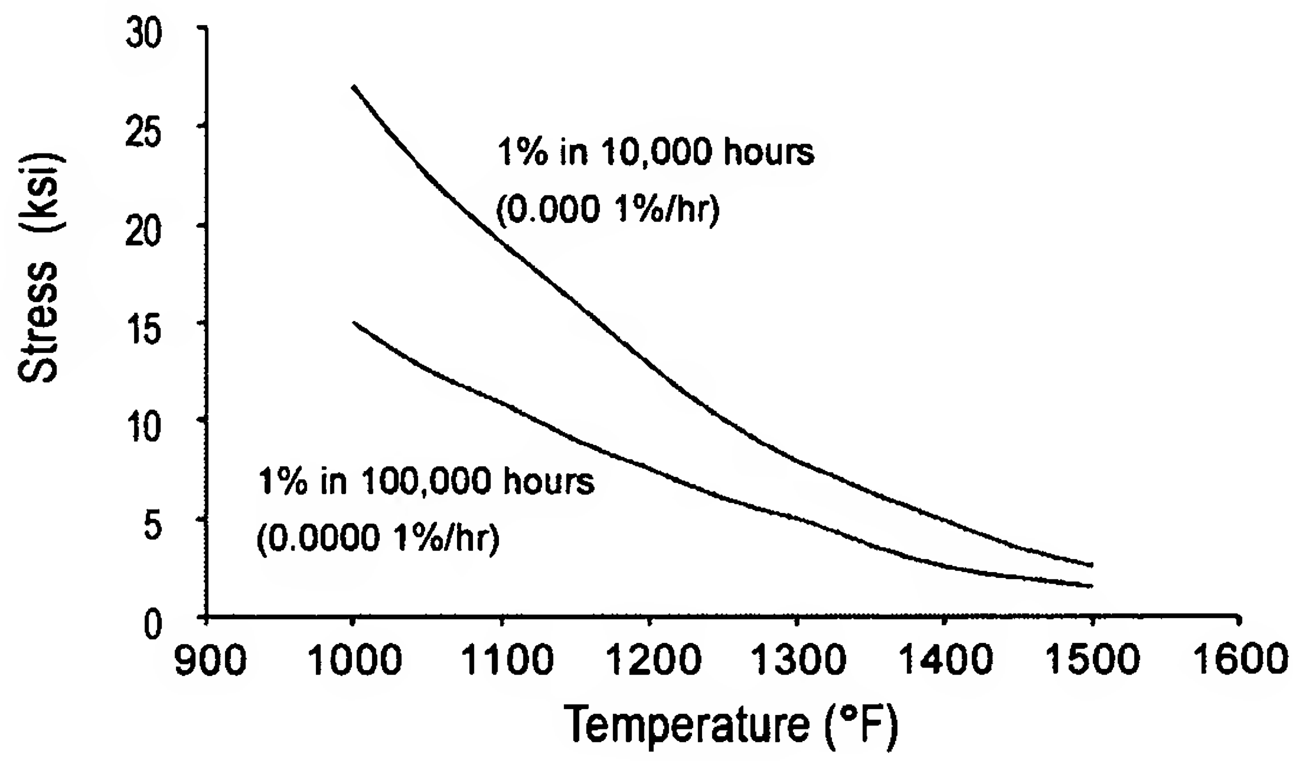
Data are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown herein.

TIME DEPENDENT ELEVATED TEMPERATURE DEFORMATION

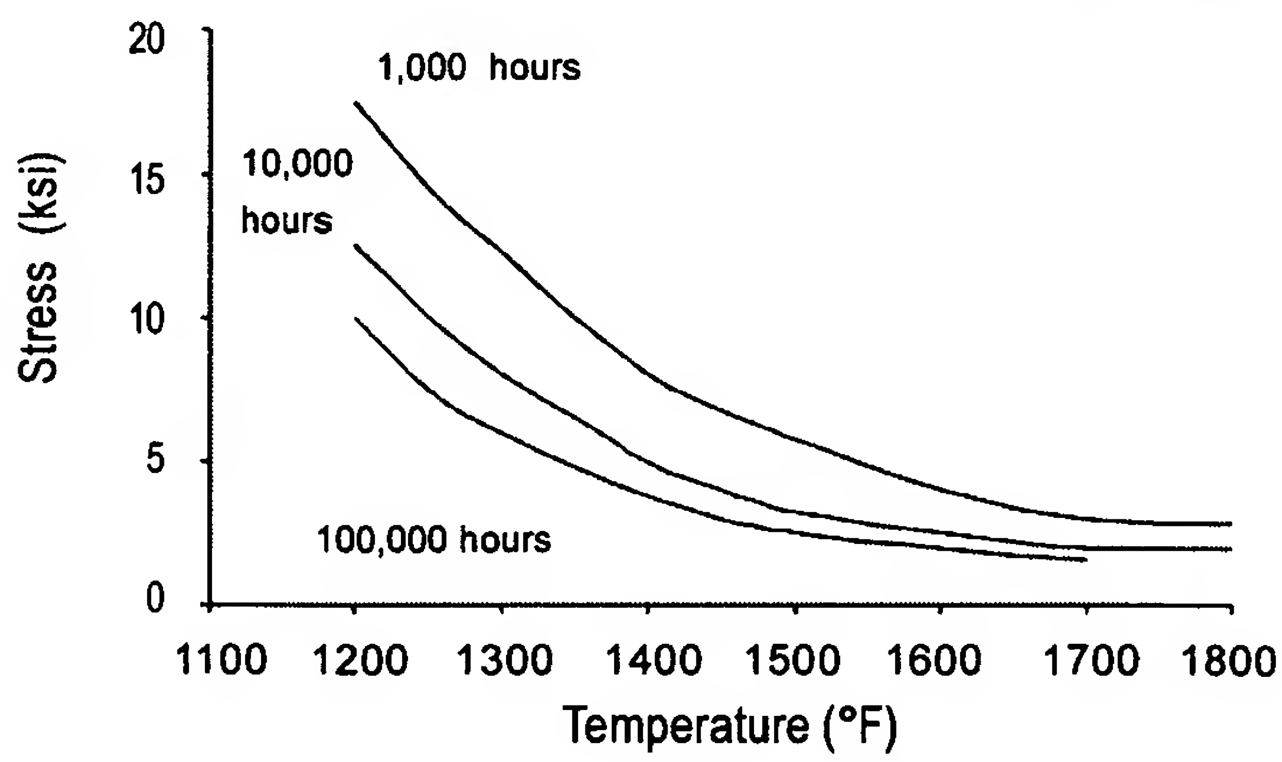
(CREEP AND STRESS–RUPTURE)



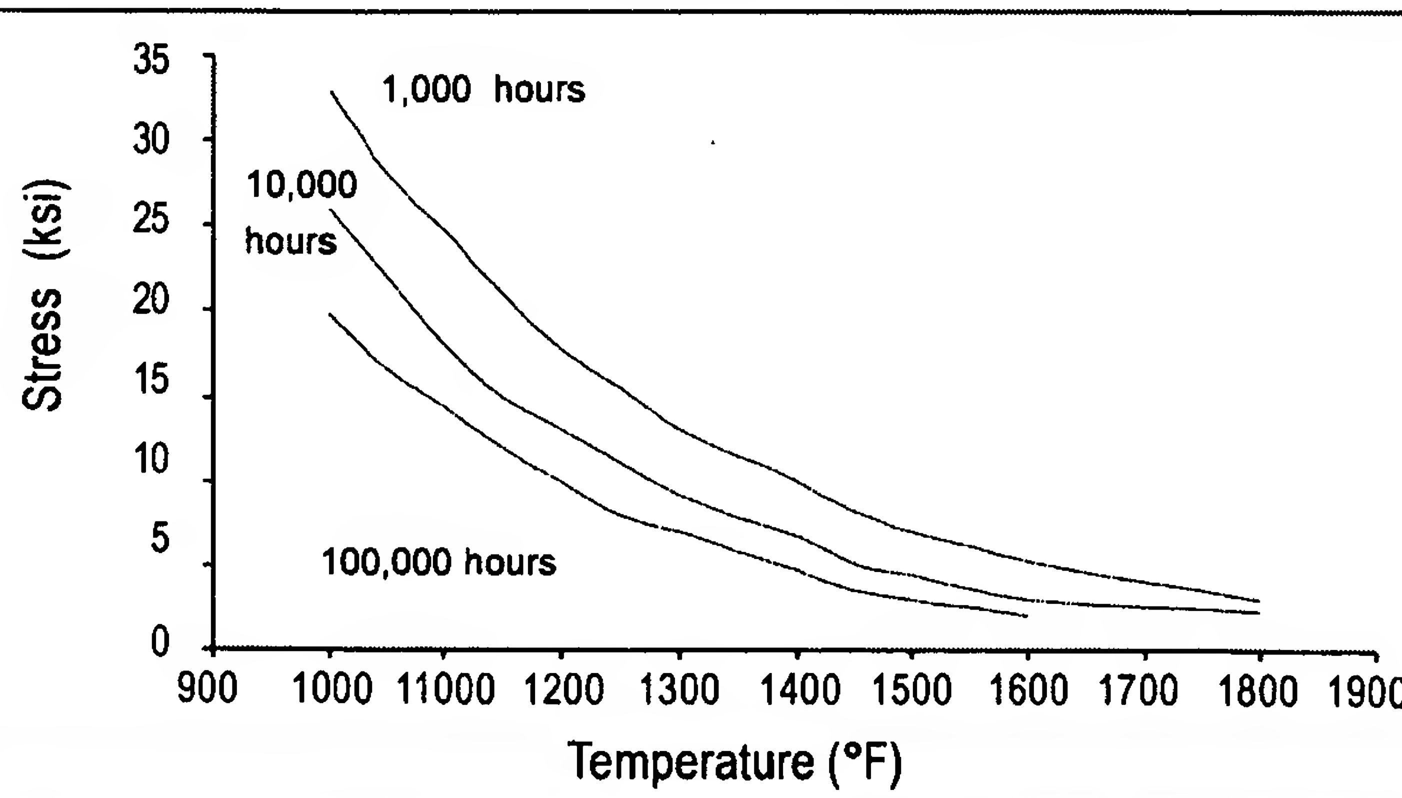
Creep strength,
annealed Type 309



Creep strength,
annealed Type 310



Rupture strength,
annealed Type 309



Rupture strength,
annealed Type 310

Data are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown herein.

AQUEOUS CORROSION RESISTANCE

Types 309 and 310 are primarily used at elevated temperature to take advantage of their oxidation resistance. However, both of these stainless grades are resistant to aqueous corrosion due to their high chromium and nickel contents. Selected corrosion test results for Type 310S are collected in the following tables. All solutions are described as concentrations by weight.

Test Solution	Plain Sample	GTAW Welded Sample
50% Sodium Hydroxide	1.2	1.3
10% Sulfamic Acid	61.9	17.2
10% Sulfuric Acid	111.8	112.3
ASTM A262 Practice B	5.3	5.3
ASTM A262 Practice C	3.8	3.8
ASTM A262 Practice E	Pass	Pass
20% Acetic Acid	0.1	0.1
45% Formic Acid	32.5	34.2
1% Hydrochloric Acid	23.2	22.3
10% Oxalic Acid	11.6	11.2
20% Phosphoric Acid	0.4	3.2
10% Sodium Bisulfate	46.1	36.6

General corrosion of Type 310S—Metal loss in mils per year (MPY) after five 48 hour test periods in boiling solutions for samples with a 2B finish

Test Solution	As–Received	Sensitized
Huey Test	3.5	6.7
Boiling 65% Nitric Acid	4.2	31.0
Boiling 70.6% Nitric Acid	3.6	18.6
Boiling 96.1% Sulfuric Acid	47.1	50.2

Huey Test results for Type 310S
(metal loss in mils per year)

Plain	Welded
6.9	10.5

10% Ferric Chloride rubber band test ASTM G–48 70°F (21.1°C), 72 hours, average of two tests (weight loss in mg/cm²)

Although their higher nickel content provides marginal improvement with respect to chloride stress corrosion cracking (SCC) compared to the 18–8 stainless steels, Types 309 and 310 austenitic stainless steels remain susceptible to this form of attack.

Test Solution	Plain Sample	Welded Sample
25%NaCl (pH=1.5)	(1) OK after 1344 hours	
	(2) OK after 1344 hours	
	(3) OK after 1344 hours	
	(4) OK after 1344 hours	—
26% Sodium Chloride	(1) OK after 1006 hours	(2) OK after 1006 hours
	(1) OK after 1006 hours	(2) Cracked after 1006 hours[1]
33% Lithium Chloride	(1) Cracked after 126 hours	(2) Cracked after 174 hours
	(1) Cracked after 120 hours	(2) Cracked after 120 hours
42% Magnesium Chloride	(1) Cracked after 30 hours	(2) Cracked after 46 hours
	(1) Cracked after 46 hours	(2) Cracked after 46 hours
50% Sodium Hydroxide	(1) OK after 196 hours	(2) OK after 196 hours
	(1) OK after 196 hours	(2) OK after 196 hours

1 Broke from bolt hole to edge

SCC results ASTM G123 boiling solutions

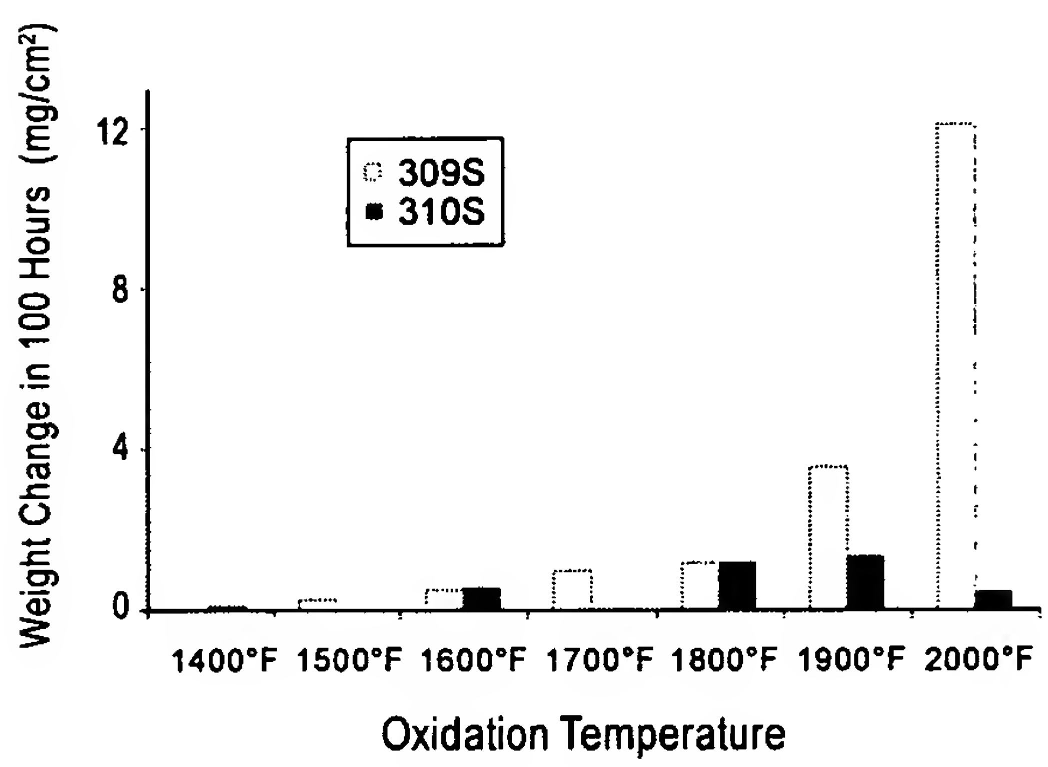
Certain applications specify the use of Type 310 stainless steel where increased resistance to aqueous corrosion is needed. An example is service in concentrated nitric acid, where preferential attack of grain boundaries may occur. In such cases the use of Type 310L may be advantageous. The high chromium content combined with restricted levels of carbon (a specified maximum of 0.015%), silicon, phosphorous, sulfur and molybdenum provide the 310L alloy with outstanding resistance to intergranular attack in this environment. Please refer to the Technical Note on this grade for more information.

ELEVATED TEMPERATURE OXIDATION RESISTANCE

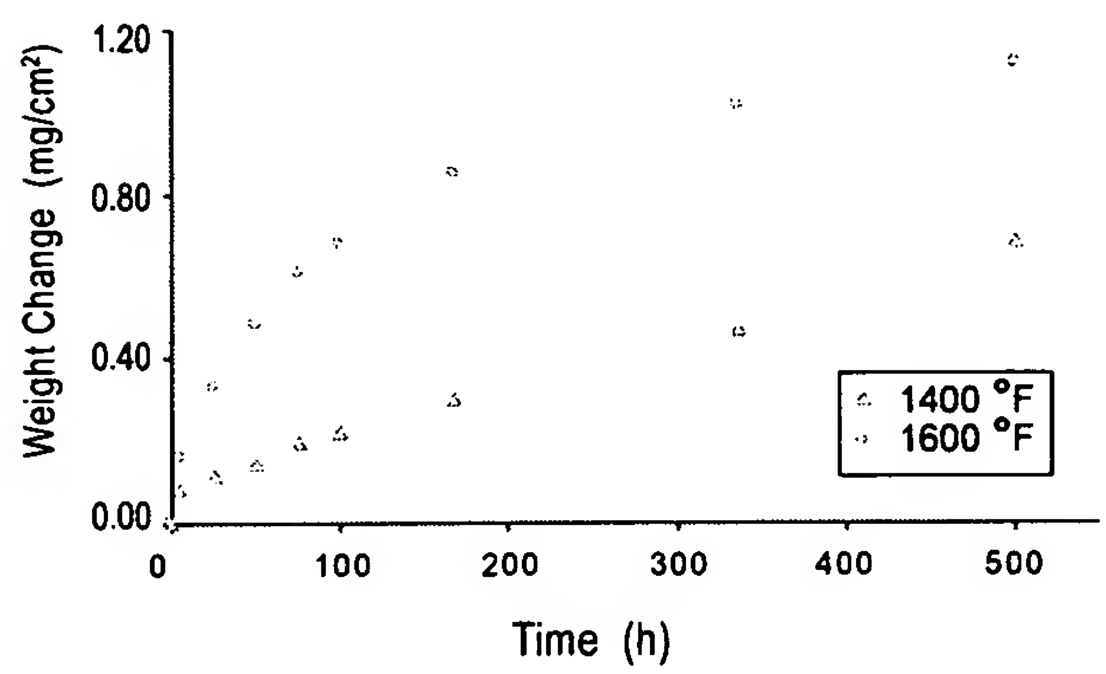
Metallic alloys will react with their surroundings to some degree under most conditions. The most common reaction is oxidation—metallic elements combining with oxygen to form oxides. Stainless steels are resistant to oxidation through selective oxidation of chromium, which forms a slow growing, very stable oxide (Cr_2O_3 or chromia). Given enough chromium in the underlying alloy, a compact and adherent surface layer of chromium oxide is established which prevents the formation of other, faster growing oxides and serves as a barrier to further degradation. The rate of oxidation is controlled by transport of charged species through the external chromia scale. As the surface scale thickens the rate of oxidation decreases dramatically because the charged species have to travel farther. This process, the high temperature analogue of passivation during corrosion at low temperatures, is known as protective scale formation.

The oxidation resistance of austenitic stainless steels can be approximated by the chromium content of the alloy. True heat resistant alloys generally contain at least twenty percent (by weight) chromium. Replacing iron with nickel also generally improves an alloy's high temperature behavior. Types 309 and 310 are highly alloyed materials, and are therefore very resistant to oxidation.

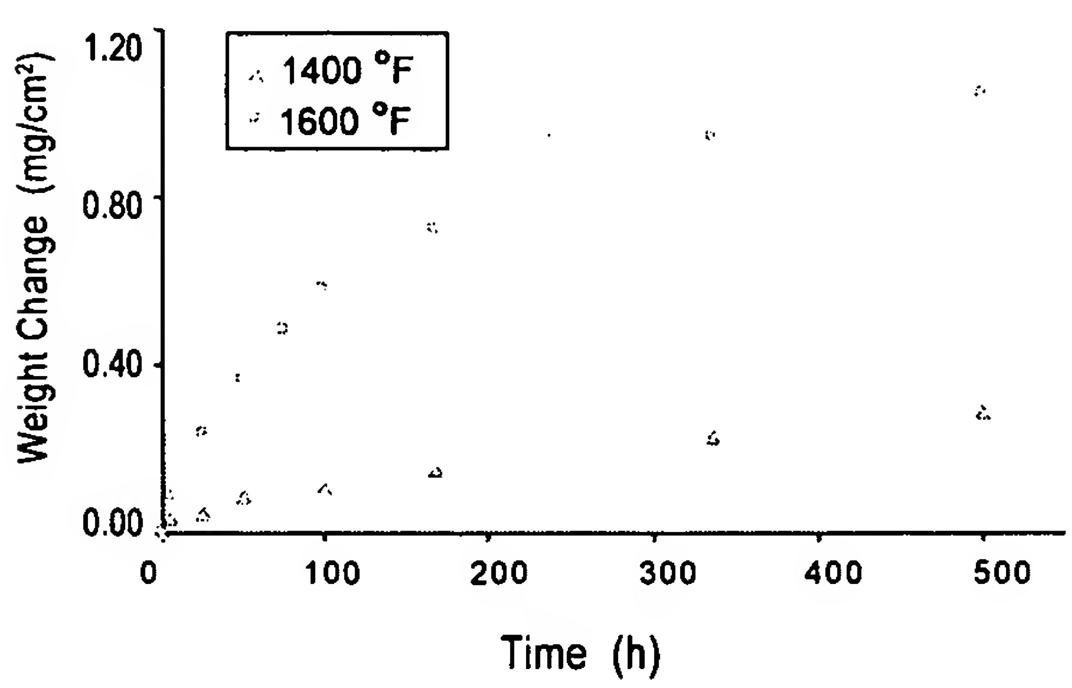
An oxidized metal sample will increase in weight corresponding to the amount of oxygen incorporated into the scale and any internal oxidation. Measuring the change in weight of a sample which has been exposed at high temperatures for a set period of time is one way to determine the oxidation resistance of an alloy. Greater weight gains typically indicate more severe oxidation.



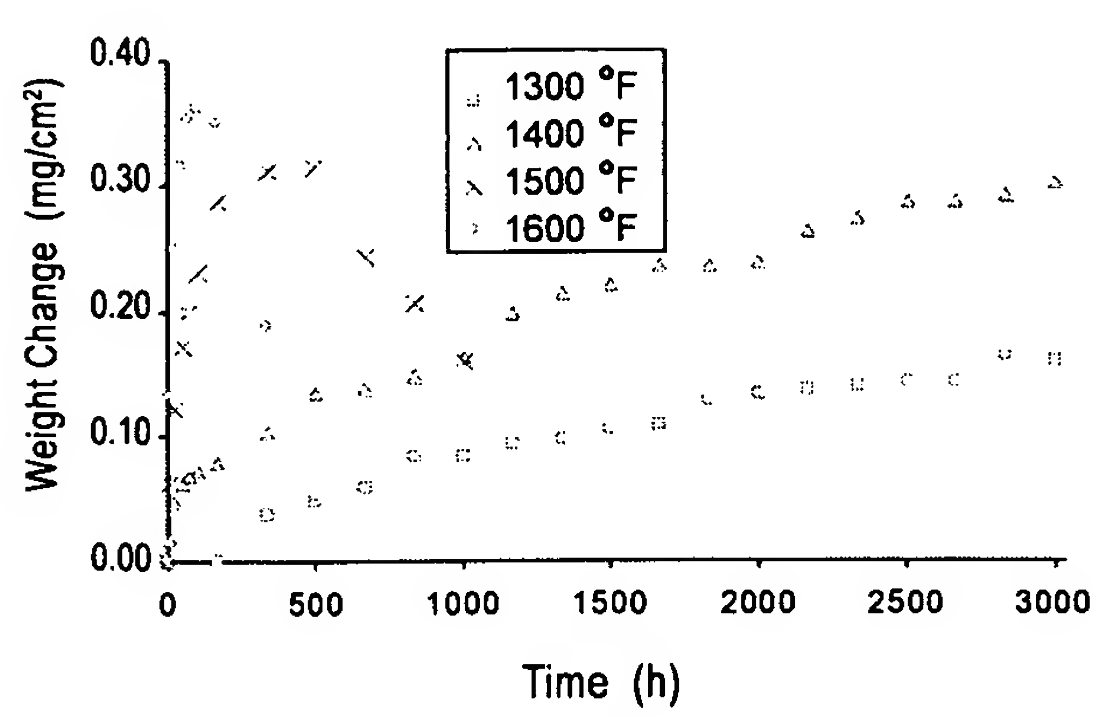
Short term oxidation data for 309S and 310S



Long term oxidation data for 309S



Long term oxidation data for 310S



Long term oxidation data for 309Si

Data are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown herein.

Oxidation is more complex than simple scale thickening. Spallation, or the detachment of the surface oxide scale is the most common problem encountered during the oxidation of stainless steels. Spallation is typically manifested by rapidly accelerating weight loss. A number of factors can cause spallation, chief among them thermal cycling, mechanical damage, and excessive oxide thickness.

During oxidation, chromium is tied up in the scale in the form of chromium oxide. When the oxide scale spalls off, fresh metal is exposed and the local rate of oxidation temporarily increases as new chromium oxide forms. Given sufficient scale spallation, enough chromium may be lost to cause the underlying alloy to lose its heat resistant properties. The result is the formation of rapidly growing oxides of iron and nickel, known as breakaway oxidation.

Very high temperature oxidation can lead to scale volatilization. The surface chromium oxide scale formed on heat resistant stainless steels is primarily Cr_2O_3. At higher temperatures the tendency is for further oxidation to CrO_3, which has a high vapor pressure. The rate of oxidation is then split into two parts—scale thickening by formation of Cr_2O_3 and the thinning effect of CrO_3 evaporation. The tendency is for eventual balance between growth and thinning with the scale remaining at a constant thickness. The result is continuous recession of the surface and consumption of the metal beneath. The effect of scale volatilization becomes a significant problem at temperatures above approximately 2000°F (1093°C) and is exacerbated by rapidly flowing gases.

OTHER FORMS OF DEGRADATION

Species other than oxygen present in the high temperature environment can cause accelerated degradation of stainless steels. The presence of sulfur can lead to sulfidation attack. Sulfidation of the stainless steels is a complex process and depends strongly on the relative levels of sulfur and oxygen, along with the form of sulfur present (e.g. elemental vapor, sulfur oxides, hydrogen sulfide). Chromium forms stable oxides and sulfides. In the presence of both oxygen and sulfur compounds a stable external chromium oxide layer often forms which can act as a barrier to sulfur ingress. However, sulfidation attack can still occur at regions where the scale has become damaged or detached, and under certain circumstances sulfur can transport across a chromia scale and form internal chromium sulfide phases. Sulfidation is enhanced in alloys containing a significant (about 25% or more) amount of nickel. Nickel and nickel sulfide form a low melting point eutectic phase which can cause catastrophic damage to the underlying alloy at elevated temperatures.

High levels of carbon–bearing species in the environment can result in undesired carbon ingress and the subsequent formation of internal carbides. Carburization generally takes place at temperatures above 800°C (1470°F) and at a carbon activity less than unity. The formation of a zone of internally carburized metal can cause undesired changes in mechanical and physical properties. Generally, the presence of oxygen will prevent carbon ingress by the formation of a protective external scale. Higher levels of nickel and silicon are somewhat effective in reducing the susceptibility of carburization. Metal dusting is a specific form of carburization attack which generally occurs at lower temperatures (350–900°C or 660–1650°F) and at a carbon activity greater than unity. It can result in catastrophic local attack via the formation of deep craters through a complex mechanism which converts solid metal to mixture of graphite and metal particles.

Nitridation can occur in the presence of nitrogen gas. Oxides are generally more stable than nitrides, so in an atmosphere which contains oxygen an oxide scale typically forms. Oxide layers are good barriers to nitrogen ingress, so nitridation is rarely a concern in air or in gases typical of combustion products. Nitridation can be a problem in purified nitrogen and is of special concern in dried, cracked ammonia atmospheres where the oxygen potential is very low. At relatively low temperatures a surface nitride film will generally form. At higher temperatures (above about 1000°C or 1832°F) the diffusivity of nitrogen is fast enough that nitrogen penetrates deep into the metal and causes the formation of internal nitrides on grain boundaries and within grains. This can lead to compromised mechanical properties.

Metallurgical instability, or the formation of new phases during high temperature exposures, can adversely affect mechanical properties and reduce corrosion resistance. Carbide particles tend to precipitate at grain boundaries (sensitization) when austenitic stainless steels are held in or slowly cooled through the temperature range 800°–1650°F (427°–899°C). The higher levels of chromium and nickel contained in these alloys results in lower carbon solubility, which tends to increase the susceptibility for sensitization. Forced quenchant (gas or liquid) cooling is recommended through the critical temperature range, particularly for thicker sections. The time at temperature required to form chromium carbides increases with decreasing carbon content. Therefore, the low carbon versions of these alloys are more resistant but not immune to sensitization. When heated at temperatures between 1200°–1850°F (649°-1010°C) for long periods of time, Types 309 and 310 can exhibit decreased ductility at room tempera-

ture due to the precipitation of brittle second phase particles (sigma phase and carbides). Sigma phase often forms at grain boundaries and can reduce ductility. This effect is reversable and full ductility can be restored by reannealing at the suggested temperatures.

Elevated temperature degradation is greatly affected by the atmosphere present and other operating conditions. General oxidation data can often be used only in estimating the relative oxidation resistance of different alloys. Allegheny Ludlum's Technical Center can supply data and prior experience pertaining to specific applications on request.

FABRICATION CHARACTERISTICS

Types 309 and 310 stainless steel are widely used in the heat treatment/process industries due to high temperature properties and corrosion resistance. As such, they are commonly fabricated into complex structures. Mild carbon steel is generally treated as the standard for performance in most metal forming operations. With respect to carbon steel, the austenitic stainless steels exhibit a significant difference — they are tougher and tend to work harden rapidly. While this does not alter the general methods used for cutting, machining, forming, etc. it does affect the specifics of those methods.

Cutting and machining the austenitic stainless steels is readily accomplished using standard techniques typically employed for common mild steel, with some modifications. Their cutting behavior can be quite different — they are tougher and tend to harden rapidly during working. The chips produced are stringy and tough and retain considerable ductility. Tooling should be kept sharp and be rigidly held. Deeper cuts and slower speeds are generally used to cut below work hardened zones. Due to the low thermal conductivity and high coefficient of thermal expansion inherent to the austenitic stainless steels, heat removal and dimensional tolerances must be considered during cutting and machining operations.

The austenitic stainless steels are readily cold formable by standard methods such as bending, stretch forming, roll forming, hammer forming, flaring/flanging, spinning, drawing and hydroforming. They work harden readily, which is manifested by steadily increasing amounts of force needed to continue deformation. This results in the need to use stronger forming machines and eventually limits the amount of deformation possible without cracking.

A relatively narrow range of temperatures can be used for effective hot working of Types 309 and 310 due to numerous environmental and metallurgical factors. Forging should start in the temperature range 1800°–2145°F (980-1120°C) and finish no cooler than 1800°F (980°C). Working at higher temperatures results in a fall off of hot ductility due to environmental and metallurgical factors, particularly the formation of ferrite. Working at lower temperatures can cause the formation of brittle second phases, e.g. sigma and/or sensitization. Following forging, the workpiece should be cooled rapidly to a black heat.

WELDING

The austenitic grades are generally considered to be the most weldable of the stainless steels. They can be welded using all of the common processes. This is generally true of Types 309 and 310. When filler metal is required, matching compositions are generally used. The elevated alloy contents of this grade can make the weld pool sluggish. If weld pool fluidity is a problem, filler metal containing silicon can help (e.g. ER309Si, ER309LSi).

Types 309 and 310 exhibit a relatively high coefficient of thermal expansion, low thermal conductivity, and form low levels of ferrite in the solidifying weld metal. These factors can lead to hot cracking. The problem can be more severe for restrained and/or wide joints. Filler metal with a lower alloy content (e.g. ER308) will increase the amount of ferrite in the weld deposit and reduce the tendency for hot cracking. The subsequent dilution of the base metal may decrease the corrosion/heat resistance of the weld.

The "S" grades are relatively low in carbon. If low carbon is required "L" electrodes (e.g. ER309L) can be used. With proper weld practices, intergranular corrosion of the heat affected zone is unlikely. Heat tint or scale should be removed to ensure complete restoration of corrosion resistance near the weld. Grinding or brushing with a stainless steel brush can be used to remove the heat tint scale. Acid pickling will also remove heat tint. Small pieces can be treated in a bath and larger pieces can be locally pickled using a special paste consisting of a mixture of nitric acid and HF or hydrochloric acid suspended in an inert filler. A thorough water wash should immediately follow, taking care to completely remove all traces of pickling paste.

HEAT TREATMENT / ANNEALING

The primary reasons for annealing these alloys is to produce a recrystallized microstructure with a uniform grain

size and for dissolving detrimental chromium carbide precipitates. To ensure complete annealing, pieces should be held in the range 2050°–2150°F (1120-1175°C) for approximately 30 minutes (time at temperature) per inch of section thickness. This is a general recommendation only—specific cases may require further investigation. When properly annealed, these grades are primarily austentic at room temperature. Some small quantities of ferrite may be present.

Oxide scale formation is inevitable during air annealing of Types 309 and 310. The scale that forms is generally rich in chromium and relatively adherent. The annealing scale generally must be removed prior to further processing or service. There are two typical methods for removing scale—mechanical and chemical. A combination of surface blasting prior to chemical scale removal is generally effective at removing all but the most tightly adherent scale. Silica sand or glass beads are a good choice for the blasting media. Iron or steel shot can also be used, but will lead to embedded free iron in the surface which may then result in surface rusting or discoloration unless the surface is subsequently pickled.

Chemical removal of scale is generally performed with mixed nitric–hydrofluoric acids. The proper bath makeup and process temperature combination depends on the situation. A typical pickling bath used consists of 5–25% HNO_3 (65% initial strength) and ½–3% HF (60% initial strength) in aqueous solution. Higher concentrations of hydrofluoric acid leads to more aggressive scale removal. Bath temperatures generally range from ambient to about 140°F(50°C). Higher temperatures result in faster descaling, but may attack grain boundaries aggressively, resulting in surface grooving. Acid pickling must be followed with a thorough water wash to remove all traces of pickling acids. Drying should then be used to avoid spotting and staining.

As noted, Types 309 and 310 consist solely of austenite at room temperature—they cannot be hardened through heat treatment. Higher mechanical strengths are attainable via cold or warm working, but these grades are generally not available in such conditions. The higher tensile and yield strengths obtainable through cold working not followed by full annealing are not stable at the higher temperatures at which these alloys are often used. Creep properties in particular may be adversely affected by the use of cold worked material at elevated temperatures. Other grades such as Allegheny Ludlum Types 301, 304, and 316 stainless steels are often processed to various levels of cold work when material is needed in the quarter, half, or full hard condition. The relevant Allegheny Ludlum Blue Sheets contain further information.

AVAILABILITY & SPECIFICATIONS

Types 309 and 310 are available as plate, sheet, and strip. These grades are widely used as high temperature/high strength alloys and are covered by a wide variety of specifications. A selected list is included here for flat rolled products—the entire list is extensive.

The specifications for Types 309 and 310 stainless steels (UNS S30900 and S31000) were developed long before the invention of modern steelmaking practices and analytical methods. As a consequence, the carbon range for these alloys is extremely broad (from zero to 0.20 percent maximum). With the introduction of modern steelmaking processes such as argon–oxygen decarburization (AOD), it was possible to produce lower carbon products, which were designated Types 309S (UNS S30908) and 310S (UNS 31008). These grades both have a carbon maximum of 0.08 percent, identical to that of standard Type 304 stainless steel (UNS 30400). All S30908 material falls within the range of the S30900 specification, and all S31008 material falls within the range of the S31000 specification. Like the S30400 specifications, the S30908 and S31008 specifications have no minimum for carbon contents. In order to ensure the creep benefits which come with having some carbon in the alloy, the 309H and 310H grades (UNS S30909 and S31009) were created. These each have a specified carbon range of 0.04 to 0.10 percent. Note that the H grades have lower maximum carbon (0.10 percent) than do the "standard" grades (0.20 percent maximum). European standards for Types 309 and 310 stainless steels differ from the corresponding North American standards, particularly in the area of silicon. These slightly higher silicon content alloys are covered by Werkstoffe Numbers 1.4828 (Type 309Si) and 1.4841 (Type 310Si).

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Relevant standards—flat rolled products (plate, sheet, strip)

Type 309	UNS S30900		AISI 309 SAE 30309
Type 310	UNS S31000		AISI 310 SAE 30310 ASTM A167
Type 309S	UNS S30908		AISI 309S SAE 30309S
Type 310S	UNS S31008		AISI 310S SAE 30310S ASME SA-240/SA-240M ASTM A240/A240M SAE AMS 5521 SAE J 405
Type 309Si	DIN 1.4828		
Type 310Si	DIN 1.4841	DIN EN 10045	
Type 309H	UNS S30909		
Type 310H	UNS S31009		ASME SA-240/SA-240M ASTM A240/A240M SAE AMS 5521

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AISI Type 309

Category	Steel
Class	Stainless steel
Type	Austenitic standard
Common Names	Chromium-Nickel steel
Designations	**Germany**: DIN 1.4828 **Italy**: UNI x 16 CrNi 23 14 **United States**: ASME SA249 , ASME SA312 , ASME SA35 ASME SA403 , ASME SA409 , ASTM A167 , ASTM A249 , ASTM A276 , ASTM A312 , ASTM A314 , ASTM A358 , AST ASTM A409 , ASTM A473 , ASTM A511 , ASTM A554 , AST FED QQ-S-763 , FED QQ-S-766 , MIL SPEC MIL-S-862 , S SAE J405 (30309) , UNS S30900

Composition

Element	Weight %
C	0.20
Mn	2.00
Si	1.00
Cr	22.0-24.0
Ni	12.0-15.0
P	0.045
S	0.03

Mechanical Properties

Properties		Conditions T (°C)	Treatment
Density (×1000 kg/m^3)	8	25	
Poisson's Ratio	0.27-0.30	25	
Elastic Modulus (GPa)	200	25	
Tensile Strength (Mpa)	515	25	hot finished and annealed (v
Yield Strength (Mpa)	205		
Elongation (%)	40		
Reduction in Area (%)	50		
Hardness (HRB)	95 (max)	25	annealed (plate, sheet, strip

Thermal Properties

Properties		Condition: T (°C)	Tr
Thermal Expansion (10^{-6}/ºC)	15	0-100 more	
Thermal Conductivity (W/m-K)	15.6	100 more	
Specific Heat (J/kg-K)	500	0-100	

Electric Properties

Properties		Conditio T (°C)	Tre
Electric Resistivity ($10^{-9}\Omega$-m)	780	25	

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